Automated knowledge base construction

9. Applications

Simon Razniewski
Summer term 2022
Outline

1. Academic projects
   • Scraping and Harvesting
   • Pattern-based text extraction and OpenIE
2. Industrial Knowledge Bases
3. Knowledge Base Question Answering
4. Semantic Web
DBpedia (2007)

- Large-scale Wikipedia infobox+category scraping
- Manually designed mappings to consolidate synonymous attributes
- See lecture/assignment 2
- Multilingual
- No persistent IDs
- For long considered the “core” of Semantic Web (see later)

Data access
- Per entity: http://dbpedia.org/page/Max_Planck_Institute_for_Informatics
- SPARQL endpoint:
  - http://dbpedia.org/snorql/?query=SELECT+%3Fitem+WHERE+%7B%0D%0A+%3Fitem+dbo%3AalmaMater+dbr%3ASaarland_University%0D%0A%7D
- Data dumps
  - https://wiki.dbpedia.org/develop/datasets
  - https://wiki.dbpedia.org/downloads-2016-10
YAGO (2007)

• Precision-oriented Wikipedia infobox+category extraction
• Subset of 76 important relations, cleaning steps (>95% precision)
• Much focus on type extraction from categories
  • “French writers” → “Writer” + “French person”
  • WordNet disambiguation and linking
• Data access
  • Per-entity access: https://yago-knowledge.org/graph/Elvis_Presley
  • SPARQL access: https://yago-knowledge.org/sparql
  • Data dumps: https://www.mpi-inf.mpg.de/departments/databases-and-information-systems/research/yago-naga/yago/downloads/
BabelNet (2012)

BabelNet is a multilingual lexicalized semantic network and ontology.

Focus on general terms, sense disambiguation, instead of named entities

http://babelfy.org/
Wikidata (2012)

- Largely supersedes YAGO and DBpedia
- Not itself built using AKBC techniques
  - Community generally disapproves of automated extraction
  - Isolated projects, e.g. https://github.com/google/sling
- Nonetheless highly important for AKBC
  - Disambiguation reference
  - Training data source (distant supervision)
- Data access:
  - SPARQL: https://w.wiki/DKU
  - Individual entities: https://www.wikidata.org/wiki/Q565400
  - JSON: https://www.wikidata.org/wiki/Special:EntityData/Q565400.json
  - Dumps: https://www.wikidata.org/wiki/Wikidata:Database_download
    - ~65 GB zipped
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NELL / Read The Web (2010)

NELL (Never Ending Language Learner) is an information extraction project at Carnegie Mellon University. It couples several learners.

Table Extraction

<table>
<thead>
<tr>
<th>Elvis</th>
<th>singer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Madonna</td>
<td>singer</td>
</tr>
<tr>
<td>Bobo</td>
<td>singer</td>
</tr>
</tbody>
</table>

Pattern Extraction

Elvis was born in Tupelo.

Constraints

marriedTo(x,y) \Rightarrow marriedTo(y,x)

Morphology

"-ism" are abstract things.

Learned Rules

marriedTo(x,y) \land livesIn(x,z) \Rightarrow livesIn(y,z)

Sales point: Continuous nature of extraction and learning

327 manually designed relations each with a few curated training examples

http://rtw.ml.cmu.edu/rtw/
Example: NELL about “MacBook”

categories

- **product** (100.0%)
  - MBL @482 (99.9%) on 09-jan-2012 [Promotion of "product:macbook" productinstanceof "hallwayitem:windows"]
  - SEAL @7 (100.0%) on 13-jan-2010 [1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74] using macbook
  - OE @806 (88.7%) on 23-jan-2014 [ ] using macbook

relations

- **createdbyagent**
  - apple001 (100.0%)
    - CPL @1024 (50.0%) on 27-oct-2016 ["arg1 iPhone and arg2"] using (apple, macbook)

- **haswikipediaurl**
  - http://en.wikipedia.org/wiki/MacBook (95.0%)
    - AliasMatcher @621 (95.0%) on 03-aug-2012 [Freebase 7/9/2012]

- **iteminvolvedwithagent**
  - apple001 (100.0%)
    - CPL @1010 (87.5%) on 04-aug-2016 ["arg1 iPhone and arg2" "arg1 releases a new version of arg2" "arg2 and iPod are trademarks of arg1"] using (apple, macbook)

- **producedby**
  - apple001 (100.0%)
    - SEAL @168 (50.0%) on 17-nov-2010 [1] using (apple, macbook)
ReVerb/OpenIE 4.0

- Knowledge base built using open information extraction
- 5 billion extractions from general web crawls
- https://openie.allenai.org/
- (see OIE lecture)
Pyramid

165 answers from 566 sentences (results truncated)

were built by aliens (25)
were Tomb (22)
were built by Egyptians (11)
is one (11)
is a structure (11)
is one of Wonders of the World (9)
were used as Tomb (9)
is built entirely of Limestone (9)
were built as Tomb (8)
is in fact (8)

Extracted from these sentences:
were built by The pyramids were built by aliens and other scientific facts. (via ClueWeb12) 4 hours 4 hours ago Well sure, but the pyramids were built by aliens so they do n’t count. (via ClueWeb12) Which is not to say that I dismiss the possibility entirely, but it is to say that I put it in the same category with questions like, "Were the pyramids were built by aliens, " or "Will the Eagles win the NFC championship game"? (via ClueWeb12)
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Industrial projects

- Google
- Microsoft
- Ebay
- Amazon
- Facebook
- IBM
- Apple
- Baidu
Google Knowledge Vault (2014)

• Ambitious project combining text extraction, semistructured extraction, and predictive models
• Apparently not in use (successors?)

[Dong, Xin, et al. "Knowledge vault: A web-scale approach to probabilistic knowledge fusion, KDD 2014]
Google: Knowledge Graph (since ~2012)

Google built its “knowledge graph”, a collection of factual knowledge, from Freebase, Wikipedia, and Web sources.

- https://developers.google.com/knowledge-graph
Lucius Pinarius

Lucius Pinarius Scarpus was a Roman who lived during the late Republic and the early Empire. He served as the Roman governor of Cyrene, Libya during the Final War of the Roman Republic.

Wikipedia

**Born:** 67 BC (age 2,085 years)

**Parents:** Atia Balba Tertia, Julia Major

**Great-grandparents:** Aurelia Cotta, Gaius Julius Caesar, Marcus Atius Balbus, Rutilia, Marcia, Lucius Aurelius Cotta, Pompeia

https://www.reddit.com/r/wikipedia/comments/dg6pnl/the_death_date_of_lucius_pinarius_wasnt_added_so/
Google: Knowledge Graph

Google uses the knowledge graph for

- Search
- Gmail
- Ads
- Its Chatbot

Ads Personalization

Make the ads you see more useful to you when using Google services (ex. Search, YouTube).

TOPICS YOU LIKE

- Beauty & Fitness
- Convenience Stores
- Home & Garden
- Parenting

TOPICS YOU DON'T LIKE (0)

Remove topics you don't like and add ones you do to make the ads you see more useful to you. Topics will also be added as you use some Google services (ex. when you watch a video on YouTube). We're working to include topics from other Google services.

+ NEW TOPIC
Microsoft: Satori & co

Microsoft builds
• a “world graph” (Satori)
• an academic graph
• a “work graph” based on user interactions in Office

...to help
• Cortana
• search?
• Windows
• companies
Ebay builds a KB of
• its products
• world knowledge

in order to
• identify duplicate products
• recommend similar products

Amazon bought TrueKnowledge/Evi, a startup that built a knowledge base from Wikipedia. The knowledge base is used for Amazon Alexa/Echo.

[amazon.jobs]
Facebook builds a KB
- of users
- of the things that users care about (celebrities, movies, etc.)

E.g., to augment messenger with
- contextual information/links
- contextual smileys
- proposed replies
- proposed actions (book taxi)
IBM: Watson

IBM sells software to build a KB to
- banks
- IT services/customer services
- defense organizations

Its showcase product is Watson.

Watson outperformed the 74-fold human winner in the Jeopardy quiz show.
Apple?

Apple appears to use a knowledge base for Siri.

Siri briefly thought Bulgaria's national anthem was 'Despacito'

Business Insider, 2017-10-05
Baidu

• Non-English languages traditionally underrepresented

• Open (academic) solutions:
  • Zhishi.me: Chinese-language equivalent of DBpedia
    • Based on Baidu Baike, Hudong Baike, Chinese Wikipedia
  • Xlore: English-Chinese alignment KB

• Baidu has apparently three internal knowledge graphs
  • https://www.mdpi.com/2071-1050/10/9/3245/htm

• Huawei building a knowledge graph?
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Evaluation

• Lecture:
  • [https://tinyurl.com/akbclec](https://tinyurl.com/akbclec)

• Lab
  • [https://tinyurl.com/akbclab](https://tinyurl.com/akbclab)
    • Tutor: Write “all”
    • If individual comments into text fields
Outline

1. Scraping and Harvesting
   • DBpedia, Yago, BabelNet, (Wikidata)
2. Pattern-based text extraction and OpenIE
   • NELL and ReVerb
3. Industrial Knowledge Bases
4. Knowledge Base Question Answering
5. Semantic Web
Question answering: Vital for information access

What are films directed by Nolan?

- Direct answers to questions
- Saves time and effort
- Natural in voice UI

Christopher Nolan / Films directed

The Dark Knight 2008
Interstellar 2014
Question answering: Vital for information access

What are the Oscar nominations of Nolan?

- **Best Picture**
  - 2018 · Dunkirk

- **Best Director**
  - 2018 · Dunkirk

- **Best Picture**
  - 2011 · Inception

- **Best Original Screenplay**
  - 2011 · Inception
Approaches to question answering

• Traditional IR-style approach: Match question with text phrases in documents
  • “What is the capital of Belgium”
  • “Brussels is the capital of Belgium”
  • Works only for simple questions
  • Misses additional conditions

• Google, Siri, Echo et al.
  • Precision much more important than recall
  • Answer origin needs to be debuggable/explainable

→ Question answering from structured sources much preferred
Question answering is a hot topic

★ QA over knowledge graphs [Abujabal et al. 2018]
★ Reading comprehension QA [Reddy et al. 2018]
★ Visual and multimodal QA [Lu et al. 2016]
★ Community QA [Hoogeveen et al. 2018]
★ Passage retrieval and sentence selection [Shen et al. 2018]
★ Non-factoid: Causal, procedural, ...
Which Oscar nominations did Nolan receive?

ChristopherNolan, gender, Male
ChristopherNolan, type, Director
ChristopherNolan, directed, Inception
ChristopherNolan, nominatedFor, BestDirector
BestDirector, type, AcademyAward
ChristopherNolan, birthDate, 30 July 1970
Which Oscar nominations did Nolan receive?

```
SELECT ?ANS
WHERE {
  ChristopherNolan nominatedFor ?ANS .
  ?ANS type AcademyAward .
}
```
Generalizing QA

★ If we can answer:
  ○ What are the Oscar award nominations of Nolan?

★ Then we should be able to answer:
  ○ What are the Cannes award nominations of Ryan Coogler?
  ○ Which Oscar award nominations did Nolan receive?
## Template-based Question Answering

★ Interpretable

<table>
<thead>
<tr>
<th>Question</th>
<th>Question template</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who is <em>Inception</em>'s director?</td>
<td>Who is <code>&lt;NOUN1&gt;</code>’s <code>&lt;NOUN2&gt;</code>?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Query</th>
<th>Query template</th>
</tr>
</thead>
<tbody>
<tr>
<td>?ANS director Inception</td>
<td>?ANS <code>&lt;PRED1&gt;</code> <code>&lt;ENT1&gt;</code></td>
</tr>
</tbody>
</table>

1 SPARQL triple pattern
Template-based Question Answering

- Generalizes to new domains

<table>
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<th>Query template</th>
</tr>
</thead>
<tbody>
<tr>
<td>?ANS director Inception</td>
<td>?ANS &lt;PRED1&gt; &lt;ENT1&gt;</td>
</tr>
</tbody>
</table>

Who is *Libya*'s president?
Who is *Messi*'s manager?

1 SPARQL triple pattern
Template-based Question Answering

★ Generalizes to new domains

<table>
<thead>
<tr>
<th>Question</th>
<th>Question template</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who plays the role of Cobb in Inception?</td>
<td>Who &lt;VERB&gt; &lt;DT&gt; &lt;NOUN&gt; &lt;PREP&gt; &lt;NOUN&gt;?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Query</th>
<th>Query template</th>
</tr>
</thead>
<tbody>
<tr>
<td>?ANS playsIn Inception</td>
<td>?ANS &lt;PRED1&gt; &lt;ENT1&gt;</td>
</tr>
<tr>
<td>?ANS role Cobb</td>
<td>?ANS &lt;PRED2&gt; &lt;ENT2&gt;</td>
</tr>
</tbody>
</table>

2 SPARQL triple patterns
Challenges with templates

★ Hand-crafted by experts

(Fader et al. 2014; Unger et al. 2013)

★ Low coverage

★ Solution: Learn templates

  ○ Question templates
  ○ Query templates
  ○ Slot alignments
Dependency-parse-based question templates

Question: What are the Oscar award nominations of Nolan?

Dependency parse

Question template (labeled nodes and edges)
Graphical query templates

Query: ChristopherNolan nominatedFor ?VAR.
?VAR awardTitle ?ANS.
?ANS type AcademyAward

Graphical Query

ChristopherNolan \rightarrow nominatedFor \rightarrow ?VAR

?VAR \rightarrow awardTitle

AcademyAward \rightarrow type \rightarrow ?ANS

Query template

?VAR \rightarrow PRED1 \rightarrow ENT

PRED2 \rightarrow type \rightarrow ?ANS

TYPE
Key task: Slot Alignments
Template-based question answering

New question

Template-based answering

Match

No answer found

Template bank

QA pairs

User feedback on answers

Similarity-based answering

Match

Question-Query log

Match

Train

Generalize

Add
Training template-based QA

★ Collecting question-query pairs difficult
★ Start with question-answer pairs instead
★ Create queries by distant supervision
★ Generalize to create slot-aligned templates
Distant supervision from Q-A pairs

Question: What are the Oscar award nominations of Nolan?

Answer: Best Director

★ Retain shortest path between question and answer entities

★ Retain answer type information
What are the Oscar award nominations of Nolan?

Answer: Best Director

Query: ChristopherNolan nominatedFor ?VAR .

?VAR awardTitle ?ANS .

?ANS Type AcademyAward

Distant supervision from Q-A pairs
Question-schema alignment

Question n-grams
- what nominations
- oscar nominations
- oscar award
- nominations of
- oscar
- what are
- oscar award nominations
- nominations
- award
- award nominations

KB schema
- nominatedFor
- awardTitle
- AcademyAward
Create Candidate Alignments

- **Bipartite graph** with edge weights (Yahya et al. 2012)
- **Weights** from lexicons $L_P$ and $L_T$ (Abujabal et al. 2017, Berant and Liang 2013)

![Diagram showing word alignments and edge weights]

- what nominations -> nominatedFor: 0.5
- what are -> nominatedFor: 0.5
- oscar nominations -> nominatedFor: 0.7
- oscar award nominations -> nominatedFor: 0.9
- nominations of -> nominatedFor: 0.9
- award -> nominatedFor: 0.7
- AcademyAward -> nominatedFor: 0.9
- awardTitle -> nominatedFor: 0.7
- oscar -> nominatedFor: 0.9
- oscar award -> nominatedFor: 0.7
- oscar award nominations -> nominatedFor: 0.9
Create Candidate Alignments

<table>
<thead>
<tr>
<th>Phrase</th>
<th>KG Predicate</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>nominee for</td>
<td>nominatedFor</td>
<td>0.8</td>
</tr>
<tr>
<td>nominations of</td>
<td>nominatedFor</td>
<td>0.9</td>
</tr>
<tr>
<td>oscar nominations</td>
<td>nominatedFor</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phrase</th>
<th>KG Type</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academy Award</td>
<td>AcademyAward</td>
<td>0.9</td>
</tr>
<tr>
<td>Oscar</td>
<td>AcademyAward</td>
<td>0.7</td>
</tr>
<tr>
<td>Oscar Award</td>
<td>AcademyAward</td>
<td>0.8</td>
</tr>
</tbody>
</table>
Optimal Mapping via ILP

★ Best alignment of items with Integer Linear Program (ILP)

★ At least/at most constraints

★ Type coherence
Optimal Mapping via ILP

★ Best alignment of items with Integer Linear Program (ILP)

★ At least/at most constraints

★ Type coherence

![Graphical representation of the mapping process involving the concepts: nominatedFor, awardTitle, nominations of, oscar, and AcademyAward.](diagram.png)
Apply Alignment to Question-Query

What are the Oscar award nominations of Nolan?

Christopher Nolan nominated for awardTitle ?VAR AcademyAward type ?ANS

Christopher Nolan nominatedFor ?VAR awardTitle ?ANS
Answering with templates

New question: What are the Cannes award nominations of Ryan Coogler?
What are the Cannes award nominations of Ryan Coogler?

RyanCoogler nominated ?VAR . ?VAR awardTitle ?ANS . ?ANS Type CannesAward

RyanCoogler awarded ?VAR . ?VAR awardTitle ?ANS . ?ANS Type GoldenGlobe

Rank queries with learning to rank and execute best query
Closing the Loop with User Feedback

★ So far, assumed all answers were correct: Pseudo-relevance
★ Pseudo-relevance degrades quality
★ Users provide feedback on answers

Question: Which Oscar nominations did Nolan receive?
Answer: Best Director
User: 🌟

★ Positive feedback:
  ○ Learn new template from question-query
  ○ Add new question-query to log
  ○ Update learning-to-rank model
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We can do AKBC — what now?

<table>
<thead>
<tr>
<th>Airport</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heathrow</td>
<td>London</td>
</tr>
</tbody>
</table>
Sources of incompatibility

Airport
Heathrow

Location
London

Microsoft

Airport Name
Heathrow Airport

City
Londres

Apple

〈airport〉
〈placeOrCity〉

[Images from Wikimedia Commons, except Oracle Company logos for illustration only]
Where do we need interaction?

• Booking a flight
  Interaction between office computer, flight company, travel agency, shuttle services, hotel, my calendar

• Finding a restaurant
  Interaction between mobile device, map service, recommendation service, restaurant reservation

• Intelligent home
  Fridge knows my calendar, orders food if I am planning a dinner
Where do we need interaction?

• Web service composition
  Interaction between client and Web services
  and Web services themselves

• Personal assistant
  Connects calendar, email, restaurants, secretary, etc.

• Merging data after company mergers
  (e.g. Apple buys Microsoft)
  Different terminology has to be bridged,
  accounts to be merged

• Merging data in research
  e.g. biochemical, genetic, pharmaceutical research data
Def: Semantic Web

Idea: We need an infrastructure that allows computers to “understand” their data.

This infrastructure shall
• allow machines to process data from others
• ensure interoperability between schemas, devices and organizations
• allow data to describe data
• allow machines to reason on the data
• allow machines to answer semantic queries

This is what the Semantic Web aims at

The Semantic Web is an evolving extension of the World Wide Web, in which data is made available in one standardized semantic format.
Reminder: RDF

RDF (Resource Description Framework) is a knowledge representation based on:
- entities
- classes
- binary relations
- labels

![Diagram of RDF relations]

- person
  - subclassOf
  - type: singer
  - label: "Elvis"
  - born: 1935
Globally identifying entities

KB1
Elvis

KB2
Elvis

KB3
Elvis

KB4
Elvis
Def: URI

A URI (Uniform Resource Identifier) is a string that follows the syntax

<scheme name>:<hierarchical part>[<query>][#<fragment>]

Examples:

• URLs
  http://elvis.com/biography.html#Birth
  All URLs are URIs,

• File identifiers
  file:///c:/users/elvis/tripToMoon.txt
  but not all URIs
  are URLs
  (“dereferenceable”)

• FTP
  ftp://elvis@nsa.gov

• Mail To
  mailto:him@elvis.com?subject=Where%20%are%20you
Each KB & each entity has a URI

Each KB on the Semantic Web has a URI:

- ElviPedia: http://elvis-alive.org/
- ElviPedia': http://elvikipedia.com/
- ElvisKB: http://elvis.org/kb/
- YAGO: http://yago-knowledge.org/

Each of them forms a namespace.

Each entity in a KB has a qualified name, which is also a URI:

URI of ElviPedia:

- http://elvis.org/kb/

Name in that namespace:

- Elvis

Qualified name of Elvis in ElviPedia:

- http://elvis.org/kb/Elvis
  (again a URI)
Each KB & each entity has a URI

http://elvikipedia.com/

http://yago-knowledge.org/

http://elvis-alive.org/

http://elvikipedia.com/Elvis

http://elvis.org/kb/

http://elvis-alive.org/Elvis

http://yago-knowledge.org/Elvis

http://elvis.org/kb/Elvis
Namespaces

http://elvis.is/king/of/sing

World-wide unique mapping to domain owner
in the responsibility of the domain owner

=> There should be no overlap

• a company can create URIs to identify its products
• an organization can assign sub-domains and each sub-domain can define URIs
• individual people can create URIs from their homepage
• people can create URIs from any URL for which they have exclusive rights to create URIs
Cross-referencing
A KB can make statements about entities defined in other KBs.

@prefix y: <http://yago-knowledge.org/>
@prefix d: <http://dbpedia.org/>

y:Priscilla y:loves d:Mike Stone .
Standard vocabulary

A KB can define vocabulary that is used by other KBs.

y:Singer
- subclasses
- superclasses
- label
- ...

AlizéeKB

y:Singer
- type
RDF and RDFS vocabularies

RDF is also a vocabulary (=KB) that defines basic notions of KB representation.

```
@prefix rdf: <http://www.w3.org/...>
```

We can use notions from this KB:

```
rdf:type
```

```
y:Singer
```

RDFS is a vocabulary (=KB) that defines basic notions for class representation.

```
@prefix rdfs: <http://www.w3.org/.../rdfs/>
  rdfs:label, rdfs:subClassOf,
  rdfs:domain, rdfs:range,
  rdfs:Class, rdfs:Resource "entity"
```

```
y:Singer rdfs:subClassOf y:Person
```

Sharing vocabularies

Shared vocabularies mean
• shared work in defining entities
• inter-operability of KBs

Some shared vocabularies have become standards on the Semantic Web. They have a standard namespace prefix.
More vocabularies

• Dublin Core (for describing documents)
  http://purl.org/dc/elements/1.1/
• Schema.org (for Web content)
  http://schema.org
• Creative Commons (types of licences)
  http://creativecommons.org/ns#
• Facebook Open Graph (for Web content)
  http://ogp.me/
• FOAF (Friend of a Friend; for contact information)
  http://xmlns.com/foaf/spec/
Dublin Core

Dublin Core is a vocabulary (=KB) of terms (=entities) for describing documents.

`dc:creator`, `dc:title`, `dc:format`,
`dc:MediaType`, `dc:language`...

```
| dc:creator | "Elvis: An auto-biography"
| dc:issued  | "1980"
| dc:title   | "All about my life & wife"
```

Note: The diagram illustrates the relationships between various Dublin Core elements and sample data. The image shows a Kenora graphic with labels pointing towards a yellow square. The labels include `dc:creator`, `dc:issued`, `dc:title`, and `dc:description` with corresponding sample values. The diagram visually represents the structure of Dublin Core metadata in a simplified manner.
Schema.org

Schema.org is a KB by Google, Yahoo & Microsoft for describing Web content.

s:Person, s:Movie, s:address, s:follows, s:worksFor, ...

s:birthDate "1935-01-08"

s:worksFor NSA

s:children

...
Creative Commons

Creative Commons provides their vocabulary in RDF.

cc:license, cc:attributionName, cc:permits, cc:Reproduction, ...
Def: Dereferenceable / Cool URI

A dereferenceable URI (also: Cool URI) is a URI that returns an RDF snippet if accessed on the Internet by an RDF client.

http://elvispedia.org/Elvis

@prefix e: <http://elvispedia.org/>
e:Elvis e:sings e:aSong.
e:Elvis e:born e:Tupelo.
...

Try, e.g., wget http://dbpedia.org/resource/Elvis_Presley -O elvis.rdf --header="Accept: application/rdf+xml"

https://www.wikidata.org/wiki/Special:EntityData/Q565400.rdf
Cool URIs can be traversed

@prefix e: <http://elvispedia.org/>
@prefix d: <http://dbpedia.org/>
e:Priscilla e:loves d:MikeStone
...

http://dbpedia.org/MikeStone

@prefix d: <http://dbpedia.org/>
@prefix rdf: <http://w3c.org/.../rdf>
d:MikeStone rdf:type d:KarateClown
d:MikeStone d:livesIn d:LosAngeles
...
Cool URIs can be traversed

The standard vocabularies (RDF, RDFS, schema.org, Creative Commons, etc.) all provide dereferenceable URIs, as do many KBs.
Interlinking on the Semantic Web

OWL and RDF are standard vocabularies for the linking.
Def: Linked Open Data Project

The goal of W3C's Linked Open Data Project is to publish and link open KBs. The project links equivalent entities and equivalent relations across different KBs.

This arrow means: equivalent entities between iServe and DBpedia have been linked.
The Linked Open Data Project

As of 2017: 10,000 KBs
The Linked Open Data Project

Existing KBs include
- US census data
- BBC music database
- Gene ontologies
- DBpedia general knowledge, + YAGO, + Cyc etc.
- UK government data
- geographical data in abundance
- national library catalogs (USA, Germany etc.)
- publications (DBLP)
- commercial products
- all Pokemon
...and many more
How do we get HTML pages to RDF?
Defining a fact with an entity object

A tag with “property” and “resource” defines a fact between subject and URI.

```html
<div vocab="http://schema.org/"
resource="http://martin.org/me" typeof="Person">
  <span property="name">Martin Th</span><br>
  <span property="homeLocation" resource="http://yago.org/Memphis">Memphis</span>
</div>
```

[http://martin.org/me] [http://schema.org/homeLocation] [http://yago.org/Memphis]
RDFa Example

Contact

Fabian M. Suchanek
Département INFRES (Office C201-6), Télécom ParisTech
46 rue Barrault
75013 Paris
France

@prefix ns1: <http://schema.org/> .
@prefix ns2: <http://www.w3.org/ns/rdfa#> .
@prefix ns3: <http://ogp.me/ns/article#> .
@prefix og: <http://ogp.me/ns#> .

<http://suchanek.name/fabian> a ns1:Person;
  og:description "full professor";
  og:image <https://suchanek.name/about/fabian.jpg>;
  og:title "Fabian M. Suchanek";
  ns1:address [ a ns1:PostalAddress;
    ns1:addressCountry <http://yago-knowledge.org/resource/FR>;
    ns1:addressLocality "Paris";
    ns1:postalCode "75013";
    ns1:streetAddress "46 rue Barrault" ];
  ns1:image <https://suchanek.name/about/fabian.jpg>;
  ns1:jobTitle "full professor";
  ns1:name "Fabian M. Suchanek";
  ns1:url <https://suchanek.name>;
  ns1:worksFor <http://www.enst.fr> .
Summary: RDFa embeds into HTML

Advantages:
• Grass root appeal
  (everybody can start annotating pages)
• No data duplication
  (all data in one file)
• Publisher independence
  (everybody can use his own attributes)

Standards that are similar to RDFa are
• Microformats
• Microdata
• JSON-LD
Search engines scrape RDFa & JSON-LD

iPhone X review: The best iPhone challenges you to think different ...
https://www.cnet.com/products/apple-iphone-x/review/ ▼
⭐⭐⭐⭐⭐ Rating: 4.5 - Review by Scott Stein - $999.00 to $999.99
Dec 22, 2017 - Apple iPhone X (64GB, Space Gray) ... The Good A great blend of handheld comfort and a big, gorgeous OLED screen. ... I had shaved my beard to test Face ID, Apple's new method for unlocking your iPhone by simply looking at it.

JSON-LD embedded in Web page:

```html
<script type="application/ld+json">
{
  "@context": "http://schema.org",
  "@type": "Product",
  "name": "Apple iPhone X",
  "description": "iPhone X is an overdue and winning evolution of the iPh"
  "image": "https://cnet1.cbsistatic.com/img/ZQICw4aW2fNpbmN34"
  "brand": {
    "@type": "Thing",
```
Search engines read licenses

Google search results for Lisa Marie Presley with images filtered by license:
- labeled for reuse
- labeled for reuse with modification
- labeled for commercial reuse
- labeled for commercial reuse with modification
- not filtered by license
Facebook Like Button uses RDFa

Elvis: Aloha from Hawaii (1973)
TV Special - 87 min - Documentary | Music

Your rating: 7.7/10
Ratings: 7,7/10 from 690 users
Reviews: 30 user | 3 critic

A 1973 concert by Elvis Presley taped at the Convention Center in Honolulu, Hawaii. This was the first program to ever beamed around the world by satellite.

@prefix og: <http://ogp.me/ns#> .

og:sitename "IMDb";
og:title "Elvis: Aloha from Hawaii (1973)";
og:type "video.tv-show";
Facebook public pages have JSON-LD

`<script type="application/ld+json">
{"@context":"http://schema.org",
"@type":"Organization",
"name":"ELVIS PRESLEY", ...
</script>`
UK and US govts publish RDF

Linked data

Who is doing what?
What are different departments doing with Linked Data?
References

• **Selected references**

  F. Suchanek, G. Kasneci, G. Weikum:
  “Yago: a core of semantic knowledge”, WWW 2007

  S. Auer, C. Bizer, G. Kobilarov, J. Lehmann, R. Cyganiak:

  Andrew Carlson, Justin Betteridge, Bryan Kisiel, Burr Settles, Estevam R. Hruschka Jr., Tom M. Mitchell:
  “Toward an Architecture for Never-Ending Language Learning” (NELL), AAAI 2010

  R. Navigli, S. Ponzetto:

  D. Vrandecic, M. Krötzsch:
  “Wikidata: a free collaborative knowledgebase”, Comm. of ACM 2014

• **Further reading**
  • qa.mpi-inf.mpg.de

• **Slides**
  • Adapted from Fabian Suchanek and Rishiraj Saha Roy
Assignment 9

- No assignment 😊

- Tutorial today: Exam questions
Take home

1. AKBC important tool for building structured knowledge
2. Wikipedia popular resource
3. Free text extraction harder but possible
4. KBs in widespread use in tech companies
   - Actual methods guarded secrets
   - Source of data not always known
5. Signature application: Question answering
   - Challenge: From unstructured user question to structured KB query
   - Schema reuse essential for (simple) machine-readability